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Construction Engineering Research Laboratory

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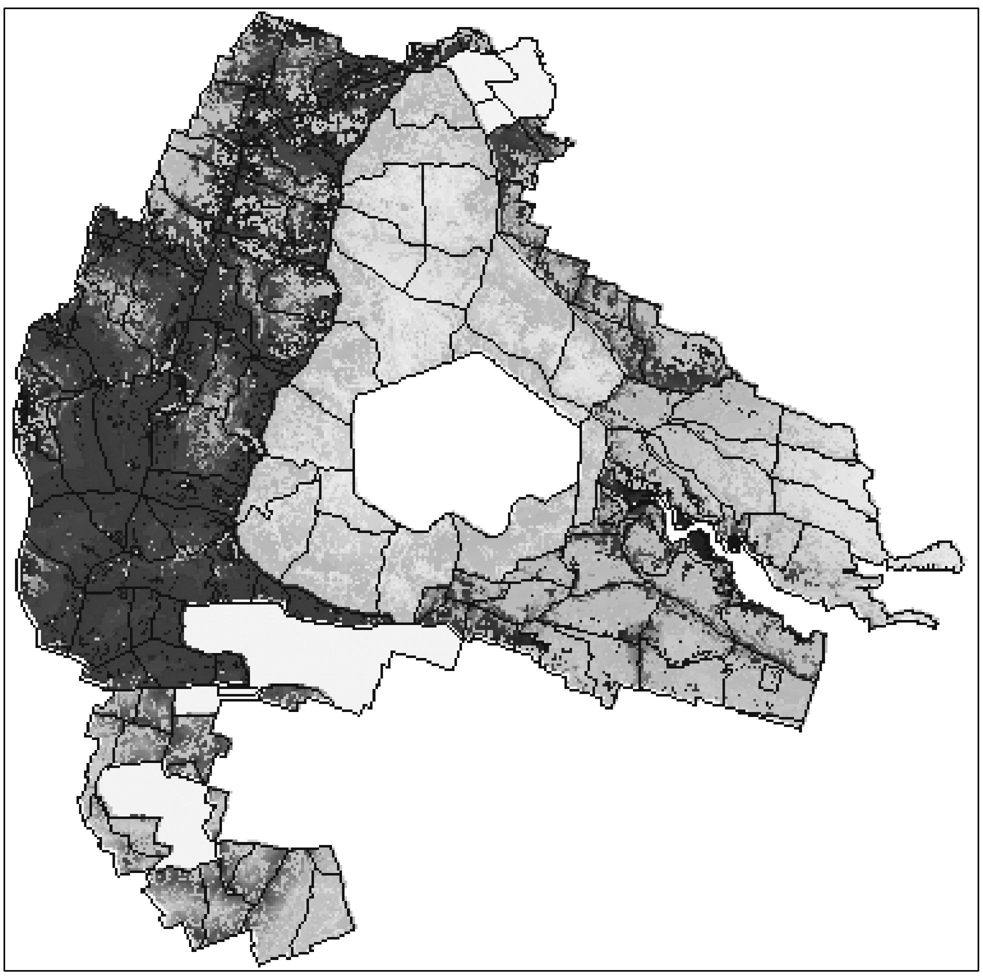
Engineer Research and Development Center

Sustainable Army Training Lands/ Carrying Capacity:

Training Use Distribution Model (TUDM)

Patrick J. Guertin and William D. Meyer

May 2002



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14. ABSTRACT

Since the early 1980s, researchers and land managers from ERDC/CERL have been developing means to quantify and predict sustainable vehicle use rates associated with maneuver training exercises for Army training lands.

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Foreword

This study was conducted for the Assistant Chief of Staff (Installation Management (ACS(IM)), Office of the Directorate of Environmental Programs (DAIM), under project 62272A89600, "Environmental Quality Technology;" Work Unit TM0 "Training Characterization and Terrain Use Analysis for Carrying Capacity Analysis." The technical monitor was Dr. Victor E. Diersing, DAIM-ED-N.

The work was performed by the Ecological Processes Branch (CN-N) of the Installations Division (CN) Construction Engineering Research Laboratory (CERL). The CERL Principal Investigator was Patrick J. Guertin. The technical editor was Gloria J. Wienke, Information Technology Laboratory. Stephen Hodapp is Chief, CEERD-CN-N, and Dr. John T. Bandy is Chief, CEERD-CN. The associated Technical Director was Dr. William D. Severinghaus, CEERD-CVT. The Director of CERL is Dr. Alan W. Moore.

CERL is an element of the U.S. Army Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers. The Commander and Executive Director of ERDC is COL John Morris III, EN and the Director of ERDC is Dr. James R. Houston.

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1 Introduction

Background

Since the early 1980's, researchers and land managers from the Engineer Research and Development Center/Construction Engineering Research Laboratory (ERDC/CERL) have been developing means to quantify and predict sustainable vehicle use rates associated with maneuver training exercises for Army training lands, referred to as Land Based Carrying Capacity (LBCC). Early efforts have included Balbach and Coin's (1984) proposed conceptual model for quantifying land use demands based on vehicle category. Warren and others (1989) integrated the Universal Soil Loss Equation (USLE) with a geographic information system to assist in planning military activities to reduce environmental impacts. Diersing and others (1989) built on this approach and created the Tracked Vehicle Day (TVD). The TVD approach characterized maneuver training areas (MTAs) by the level of vehicle use that could be sustained before erosion rates exceeded acceptable levels. All these efforts were focused primarily on determining the effects of current training events on the landscape, and were not developed as tools to predict long-term conditions based on future use.

Since these early efforts, two new projects have been undertaken. The first is the Army's current standard for determining carrying capacity, this being the Army Training and Testing Area Carrying Capacity (ATTACC) methodology (Anderson et al. 1996, U.S. Army Environmental Center 1999). Similar to early efforts, ATTACC bases carrying capacity on erosion levels. In addition, it adds the ability to estimate costs associated with land rehabilitation as a result of use, thus allowing the methodology to be used in the standard business processes used by the Army to calculate funding requirements for training. The second model, the Ecological Dynamics Simulation model (EDYS), is based on successional dynamics of plant communities in MTAs (McLendon, Childress, and Price 1999). EDYS surpasses early efforts because it goes beyond soil erosion to measure sustainable use levels by incorporating plant community variables and biodiversity. In addition, EDYS is designed to predict future training land conditions, allowing land managers to assess future land conditions and experiment with alternate management strategies.

The TVD and other early methods treated the impacts of training activities on the landscape as uniform occurrences. This assumption of uniformity does not reflect the effects of topographic, vegetation, and other environmental influences on the distribution of land use (Dubois 1994, Krzysik 1994). The ATTACC methodology uses a variety of procedures based on slope, vegetation, and similar factors to represent the distribution of training-related impacts as training events occur (Guertin, Rewerts, and DuBois 1998). To incorporate the effects of maneuver impacts as ecological stressors into the EDYS model, ERDC/CERL researchers developed the distribution pattern ideas used within ATTACC and incorporated them into a geographic information system (GIS) environment to allow for long-term distribution and intensity estimations. The product resulting from this effort is the Training Use Distribution Model (TUDM).

Model output represents the accumulative impacts of maneuver training over extended periods of time (1 year or more), with output calculated at both monthly and yearly intervals. These intervals coincide with vegetation growth functions in the EDYS model (McClendon, Childress, and Price 1996). Output takes the form of GIS layers representing the following levels of vehicle impact at a 50 meter X 50 meter grid scale: (1) percentage of cell not impacted by vehicle traffic, (2) percentage of cell impacted by 1 to 5 vehicle passes, (3) percentage of cell impacted 5 or more times by vehicle traffic, and (4) average tracking per cell. These levels of impacts were defined based on the soil impacts of vehicle traffic reported by Thurow, Warren, and Carlson (1995).

Objective

The Training Use Distribution Model was developed to provide long-term predictions of distributions and intensities of off-road Army maneuver-training impact for carrying capacity and other ecological simulation models, especially EDYS.

Approach

Model development was based on the following criterion; the use of simple models and existing installation field and GIS data to facilitate quick, low-cost implementation to a variety of Army installations. Additionally, model output needed to be in an easily accessible GIS format to capture spatial patterns and to interface with ecological models that function in a GIS environment, preferably using commercial off-the-shelf (COTS) software. Products of this approach include both TUDM and a stand-alone subcomponent of TUDM, the Maneuver

Impact Distribution Map (MIDM). This report contains an in-depth description of TUDM structure and architecture, along with the individual components.

Scope

The current working version of TUDM was developed for Fort Hood, Texas. The examples used in this report are specific to Fort Hood; however, the model is easily transferable to other installations.

Mode of Technology Transfer

The TUDM is available from the Engineer Research and Development Center/Construction Engineering Research Laboratory, Ecological Processes Branch, P.O. Box 9005, Champaign, IL 61826-9005.

This report will be made accessible through the World Wide Web (WWW) at URL:

http://www.cecer.army.mil

2 Training Use Distribution Model

Framework

Given the criterion outlined in the "Approach" section and an initial scoping of resources available, a conceptual model framework was devised. The framework had the following six components:

I. User Input Mechanism

II. Maneuver Impact Distribution Map (MIDM)

III. Event Schedule Database

IV. Event Placement Database

V. Intensity Calculation Submodel

VI. Output Mechanism

Each component of the framework is represented in TUDM as a series of mathematical/statistical models, an information database, or the user interface.

The User Input Mechanism is a graphical user interface (GUI) that allows model users to construct training scenarios for impact simulation. Data input into the front end includes the types and quantity of maneuver exercises to be simulated, as well as dates and locations. Examples of the GUI, along with programming details are discussed later.

The primary elements of the TUDM framework are the MIDM and the Event Schedule database. TUDM predictions are based on the idea that military maneuver training events can be described in terms of miles driven, and average vehicle track widths per event. Distance multiplied by track width results in area tracked, which is then transferred to the MIDM. The MIDM provides a probability surface, which allows vehicle traffic to be allocated to the MTA landscape based on slope, vegetation structure, and other factors that influence where disturbance occurs. A detailed description of MIDM development is provided in the section entitled "Maneuver Impact Distribution Map." The event database is populated with event data including miles trafficked, vehicle types, and average vehicle track widths.

The Event Placement Database, Intensity Calculation Submodel, and Output Mechanism round out the internal workings of TUDM. The Event Placement Database contains probability information for placing exercises in historically accurate MTAs when locations are not specified by the user. The Intensity Calculation Submodel is based on a binomial distribution (impacted/nonimpacted) and calculates the percent of area within each grid cell that is impacted at different intensities (none vs. single vs. multiple vehicle passes). The output mechanism currently exists as options to produce GIS map layers in two formats (Arc/Info's* Arc GRID raster map, or Geographic Resources Analysis Support System [GRASS] ASCII raster map) and an accompanying map viewer.

Model Architecture

Object-Oriented Method

TUDM was developed in the Visual Basic 6.0 and Java 1.2 programming languages. Object-oriented principles were applied in TUDM through the implementation of Visual Basic form-level classes and the creation of three custom classes. Classes form the basis for objects by defining an object's properties and methods. Properties refer to data members needed by an object; and methods are processes that the object performs. An example of an object used in the TUDM program is the Exercise object, where exercises are constructed to be grouped into scenarios for model analysis. When an object needs to perform an activity it is instantiated (created) from its base class. The properties and methods defined for the class form the interface between the object and the class. The properties for the class are set through the interface. Through the use of this approach, programs are more easily maintained. In the event of an error (bug), the error only needs to be corrected in the base class for the fix to be propagated throughout the entire program. Objects can also broadcast messages to each other through the use of an event. This is useful when you need to let one object know that another object has completed a processing activity.

* Arc/Info is a product of ESRI, 380 New York St., Redlands, CA.

Class Architecture

TUDM is composed of five main components: a front-end GUI, a back-end processing architecture, a Microsoft Access database of Army doctrine training maneuver inputs, utility modules, and an HTML help system. Figure 1 illustrates the five main components and their subcomponents.

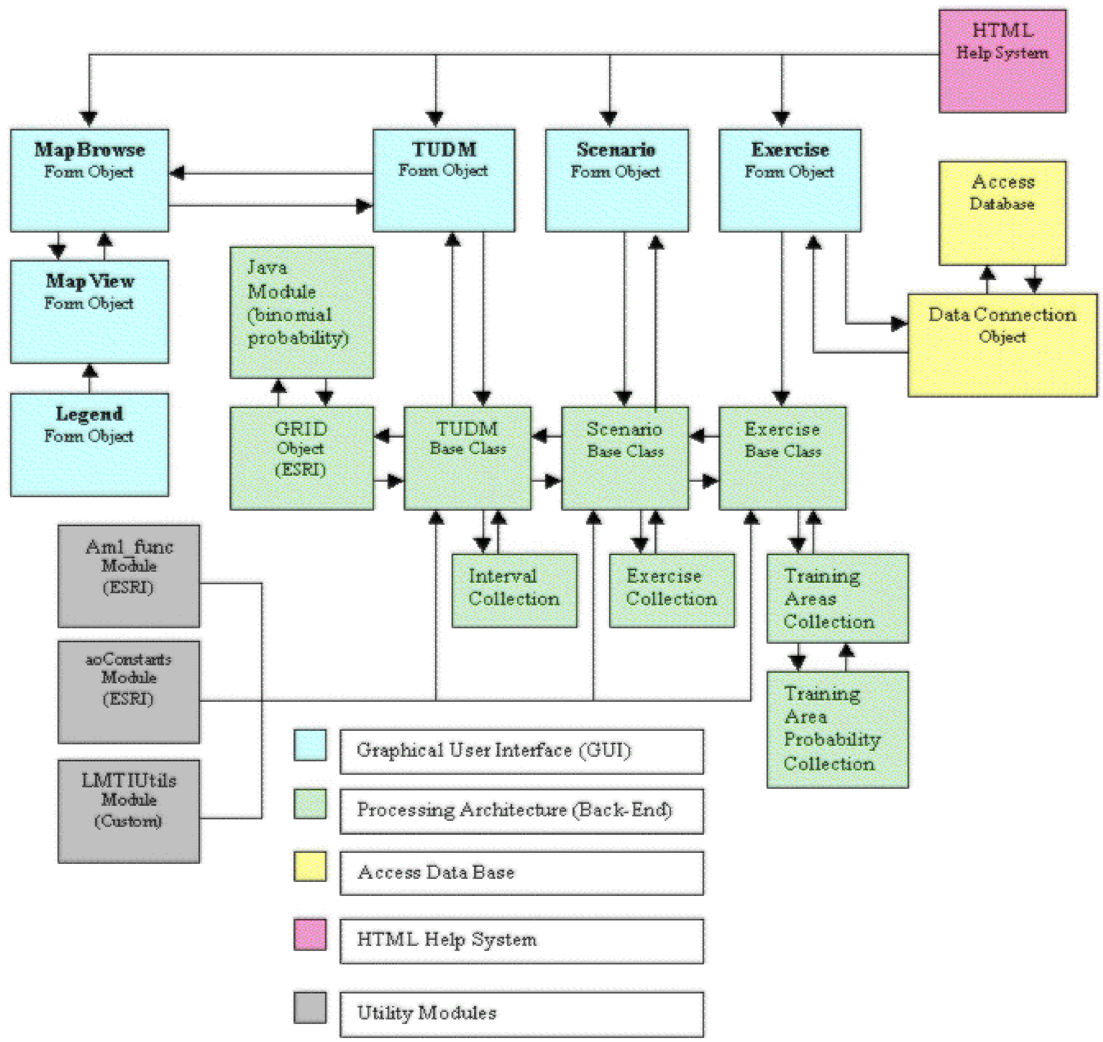

Figure 1. TUDM main component diagram.

The GUI (Figure 2) was developed to provide the means for manual interaction with TUDM. Working from the main form the user would step through a series of input screens to parameterize a model run. This interaction is expressed in the object diagram shown in Figure 3.

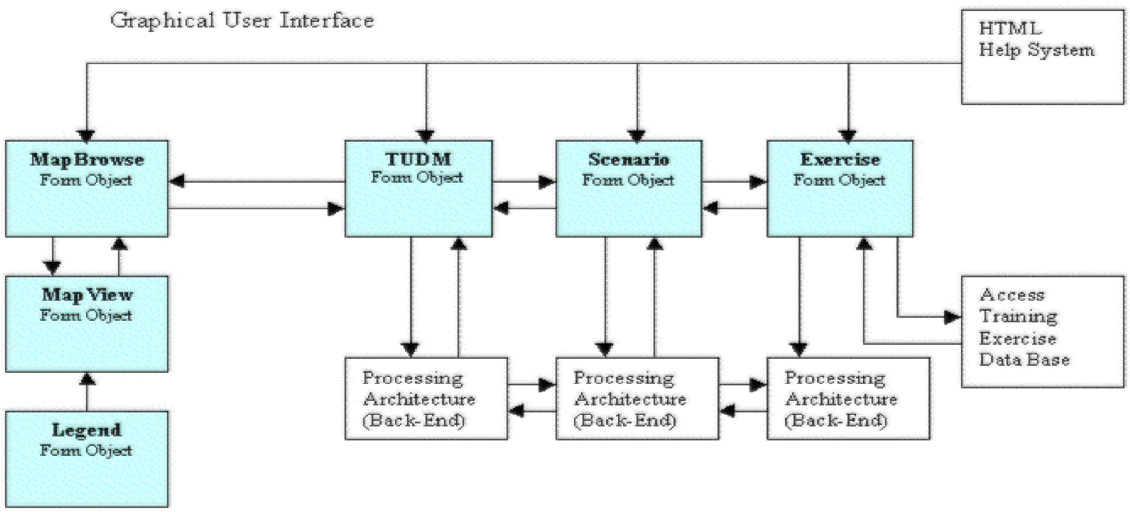

Figure 2. Graphical User Interface diagram.

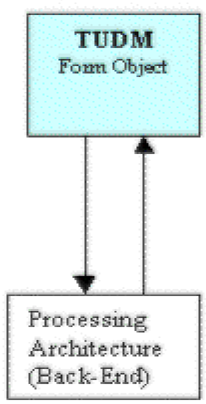

Figure 3. GUI interaction object diagram.

Figure 4 shows the main model input form. The user begins by selecting from the Maps section the input maps necessary for model processing. Clicking on the Select button for the Impact Map executes the TUDM Map Browse object interaction (Figure 5) yielding the Map Browser selection screen (Figure 6).

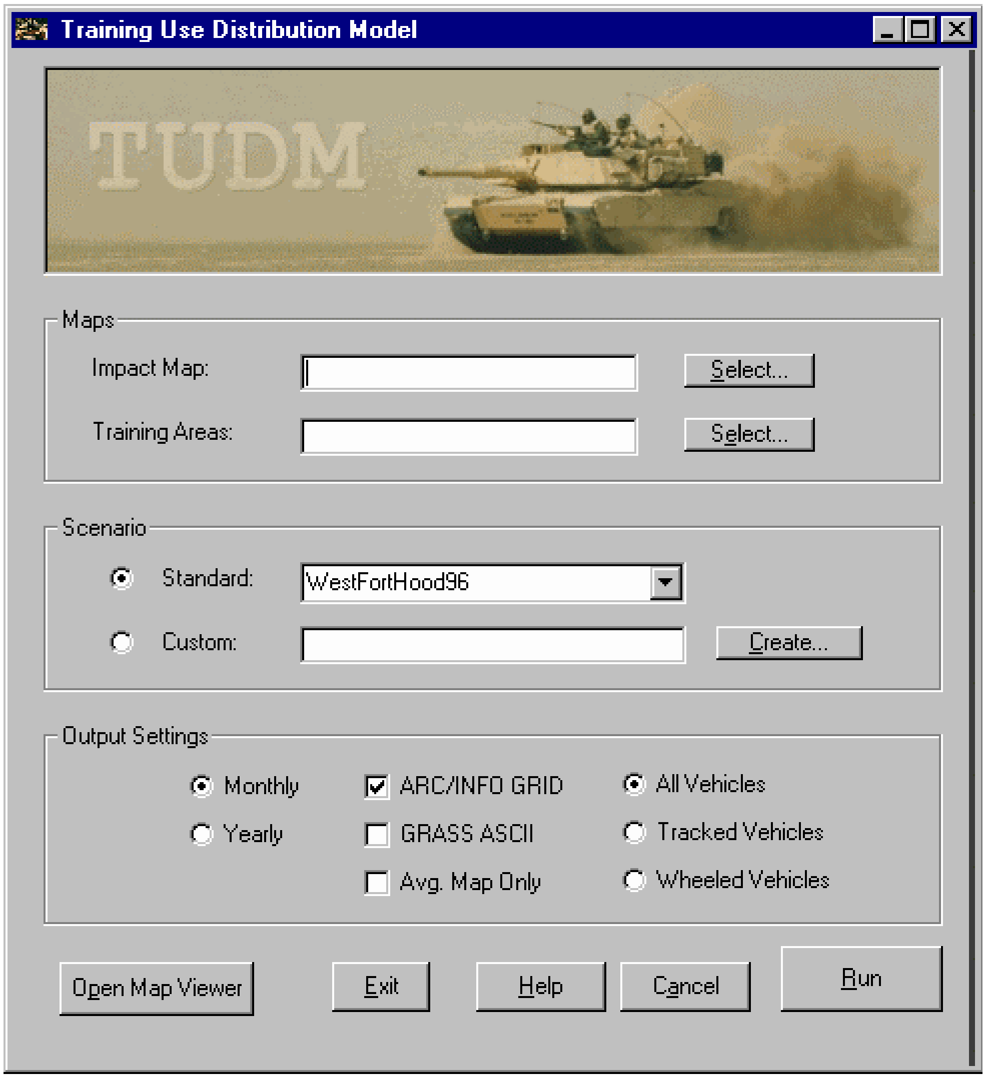

Figure 4. TUDM main model input screen.

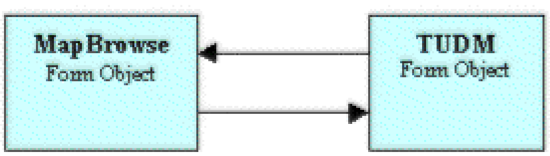

Figure 5. TUDM Map Browse object interaction.

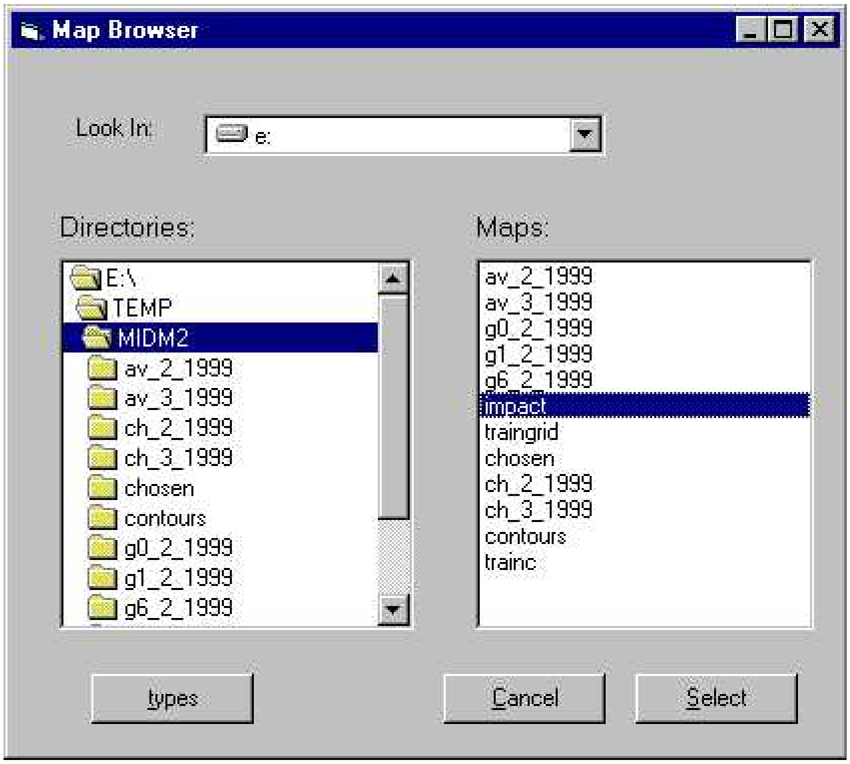

Figure 6. Map Browser selection screen.

Highlighting and clicking on the Select button will select the impact map for model processing. This same process is repeated to select the Training Areas map.

The user then moves to the Scenario section of the main form (Figure 4) and either selects a predefined scenario or decides to create a custom scenario. If a custom scenario is chosen by selecting the custom radio button and clicking on the create button, the scenario section of the object diagram executes (Figure 7).

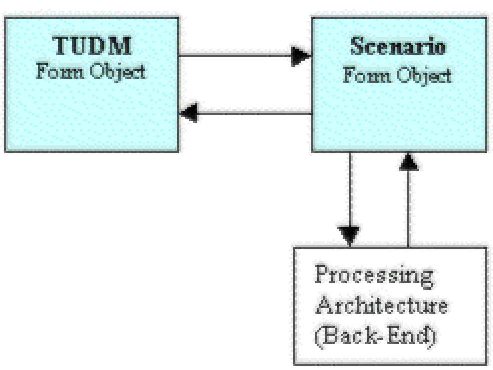

Figure 7. Scenario generation object diagram.

Through the Scenario Builder (Figure 8), the user names the scenario to be built, sets the beginning and end dates for the scenario, and begins to assemble exercises to be included in the scenario. Clicking on the Add button will execute a section of the object diagram (Figure 9) and bring up the Exercise Selection Form (Figure 10).

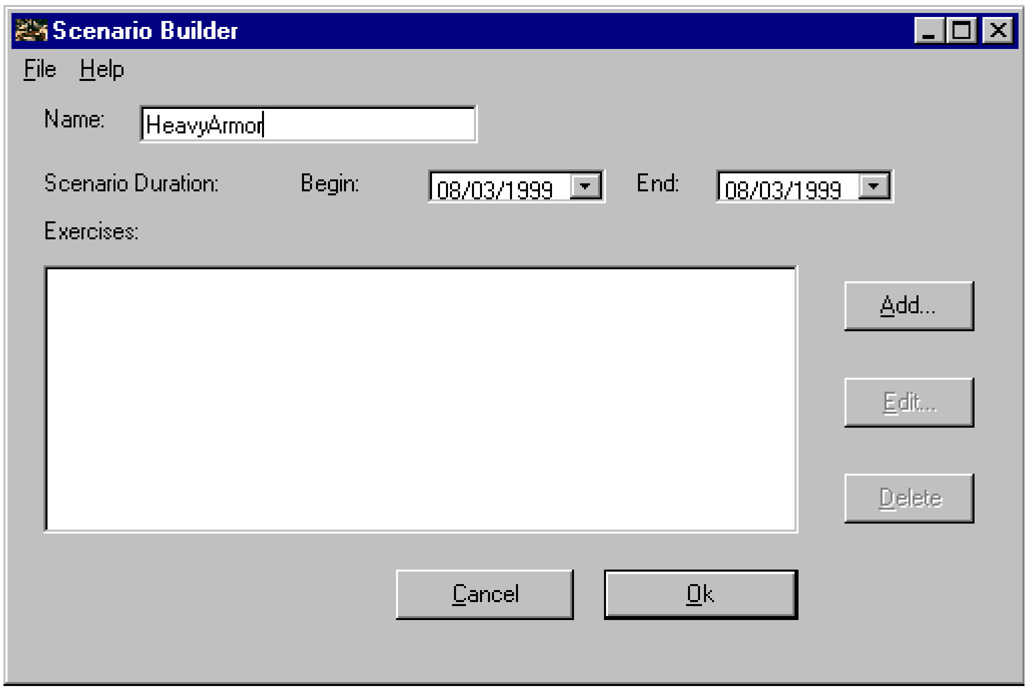

Figure 8. Scenario Builder screen.

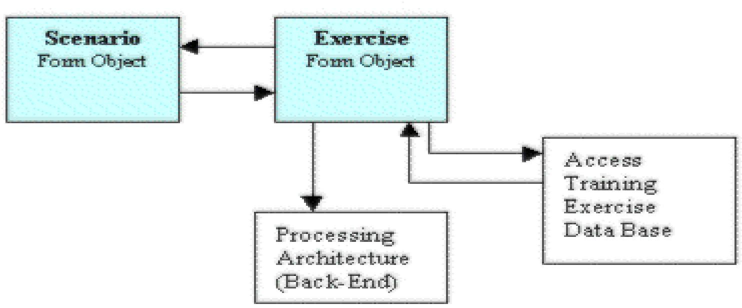

Figure 9. Exercise selection object diagram.

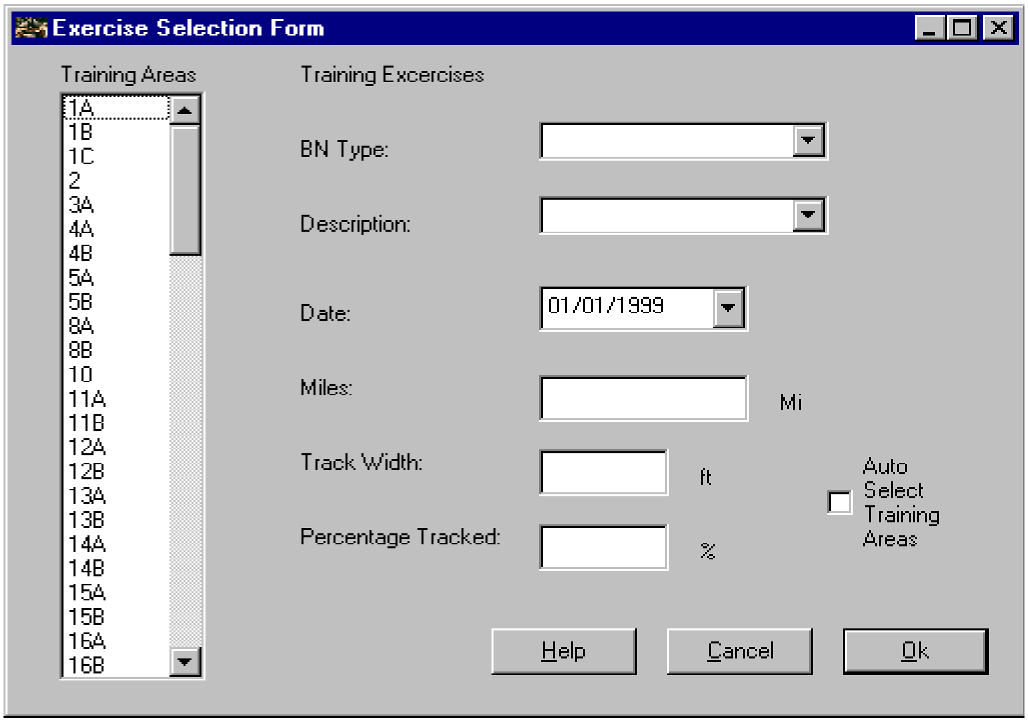

Figure 10. Exercise Selection Form.

The Exercise Selection Form is directly linked to the Access database of Army Doctrine exercise descriptions. When the user selects a battalion type (BN Type) and a description from the drop down list boxes, a query is executed that returns the miles, track width, and percentage tracked from the database for use as model inputs. If the exercise location is unknown, the "Auto Select Training Areas" check box allows the system to automatically select a training area based on a probability of past exercise patterns. Once the user is satisfied with the selections, clicking the "Ok" button will add the exercise to the scenario. The user may continue to add exercises to the scenario or return to the main screen to run the model.

The last element of the GUI is the ability to view model outputs through the Map Viewer object. Selecting the "Open Map Viewer" button on the main screen will execute the Map Viewer section of the object diagram (Figure 11), which brings up the Map Viewer Form (Figure 12).

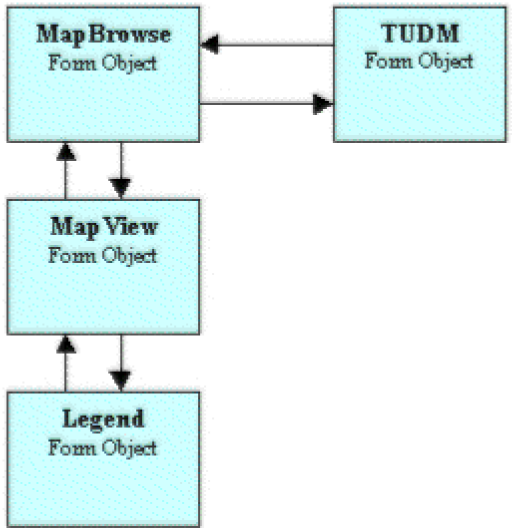

Figure 11. Map Viewer object diagram.

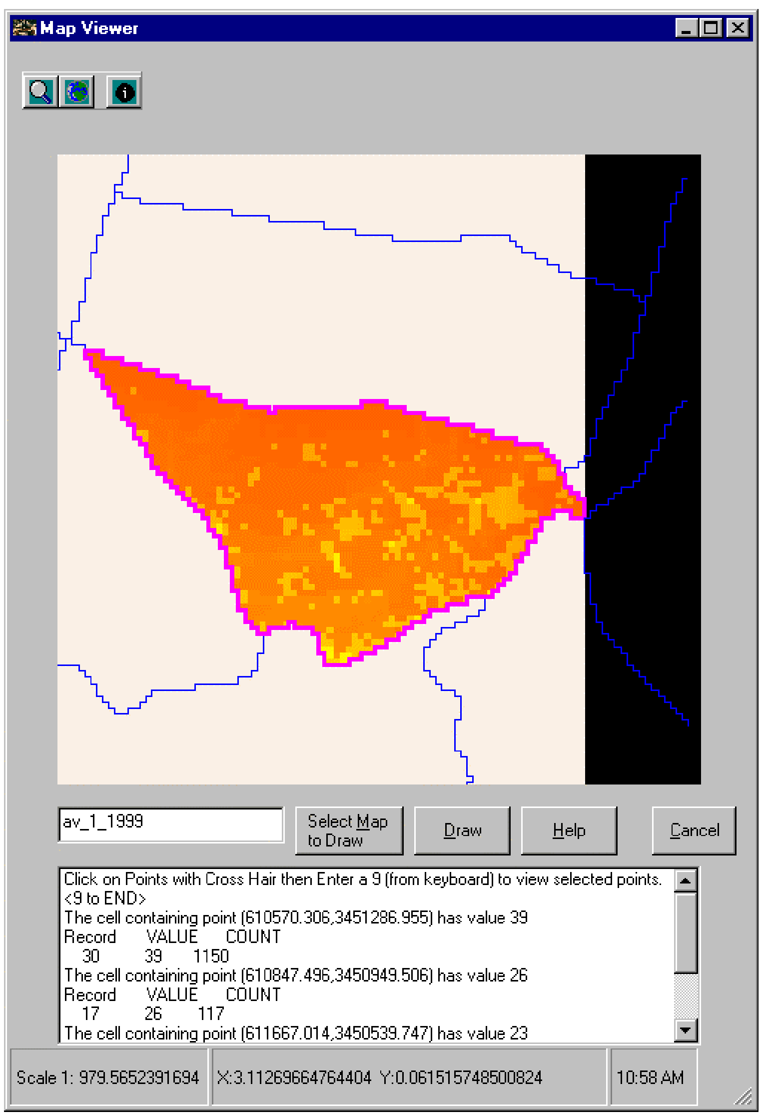

Figure 12. Map Viewer Form.

When the user selects a map to view, a legend describing the map's contents also displays (Figure 13). Through the Map Viewer the user can view outputs from the model, zoom in, zoom out, or query cell locations for model output values.

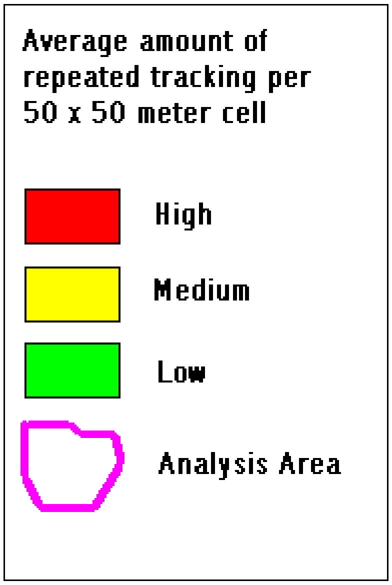

Figure 13. Map Viewer legend.

The processing architecture (Figure 14) was designed to fully leverage TUDM's ability to integrate on a machine level with another program or with a different front-end GUI without the need for code rewriting, thus keeping with the intent of following an object-oriented design paradigm. The design allows any program or GUI to parameterize the model, provided it correctly sets the input accessors.

Once the input parameters are set through the GUI, the model can run. During the run, the TUDM Base Class Module maintains model control (Figure 15).

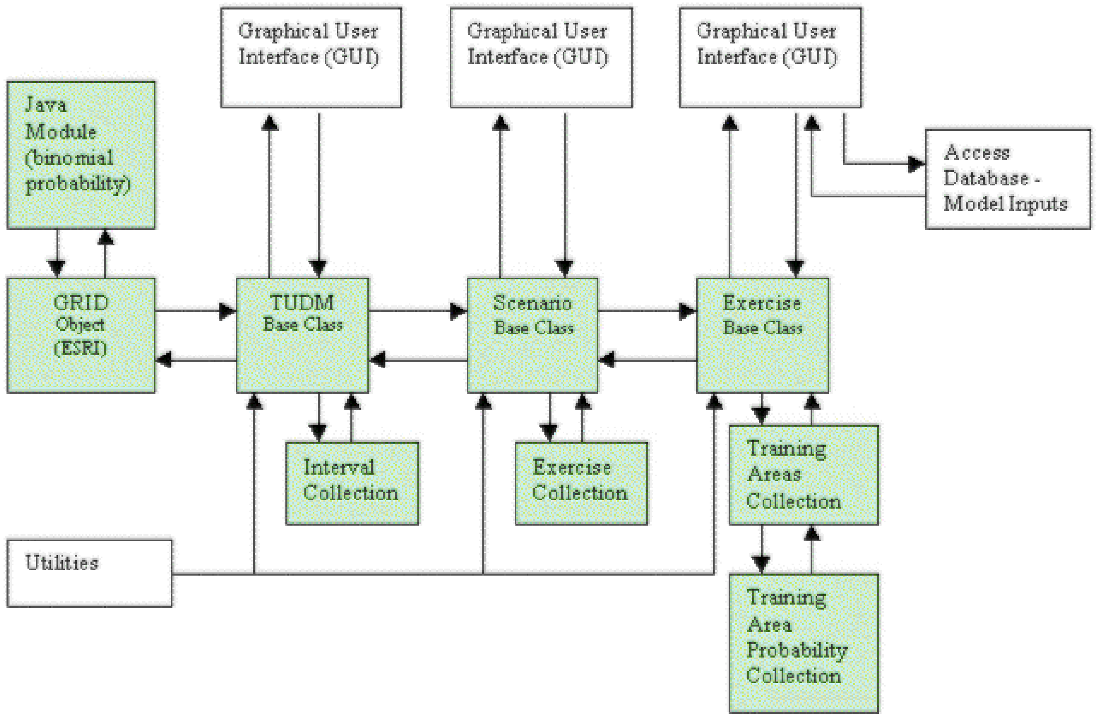

Figure 14. Processing architecture (back-end).

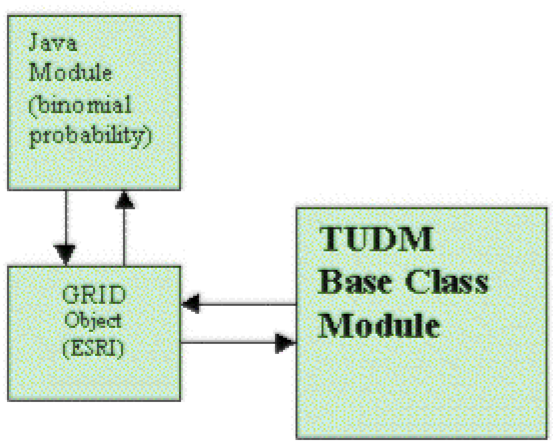

Figure 15. TUDM Base Class Module object.

The TUDM module cycles through a series of loops and subroutines while it executes the analysis code. The model begins by sorting the interval collection into yearly or monthly intervals. It then sorts through the scenario, grouping the exercise inputs and training areas into a processing list. At this point the model works with one 50- x 50-meter grid cell at a time processing the inputs against the Maneuver Impact Distribution Map values through the ArcInfo GRID Control object and the Java binomial probability subroutine. This interaction is accomplished using a combination of Arc Macro Language (AML) procedures, GRID processing, and system commands as depicted in the following section of code.

```
Public Sub makeProbabilityMaps(SelGrid As String, width As Double)
'Set up analysis environment
grid.Command "verify off"
grid.Command "mape " & SelGrid
grid.Command "setwindow " & SelGrid
'A track is one pass over a cell
'A cell is 50 x 50 meters
grid.Command "tracks = int( " & SelGrid & " / " & width & " / 50 )"
'Write values to a file (one record for each unique cell value
'in the exercise area)
grid.PushString "ARC"
grid.PushString "SELECT TRACKS.VAT"
grid.PushString "OUTPUT ../VALUES.DAT INIT"
grid.PushString "PRINT VALUE"
grid.PushString "QUIT STOP"
grid.Command "arc info"
'Determine number of records in that file
Dim nClasses As Integer
grid.Command "&describe tracks"
nClasses = grid.GetVariable("grd$nclass")
'Call Java program that calculates probability
'binprob <filename> <rec_count> <cat_low> <cat_high> <resolution>
'<track_width> <int factor>
Dim binprob As String
Dim fact As Double
Dim cutoff As Double
```

```
binprob = "E:\JavaSoft\JRE\1.2\bin\Java -classpath E:\TUDM2 _ Binomial-
Probability"
fact = 1000000
cutoff = 200
'Class 0
grid.Command "&sys " & binprob & " values.dat " & nClasses & " 0 0 _ 50 " &
width & " " & fact & " " & cutoff
grid.Command "grid0 = float( reclass( tracks, binprob ) ) / " & fact
'Class 1-5
grid.Command "&sys " & binprob & " values.dat " & nClasses & " 1 5 _ 50 " & _
width & " " & fact & " " & cutoff
grid.Command "grid1_5 = float( reclass( tracks, binprob ) ) / " & fact
'Class 6 +
grid.Command "grid6 = 1 - ( grid0 + grid1_5 )
grid.Command "avgmaped = " & SelGrid & " / 50 / 50"
End Sub
```

Java Subroutine

Since the TUDM model relies on a binomial distribution to distribute training miles across the landscape, it was determined that a high level of numerical accuracy was needed to ensure proper placement of maneuver impact miles. A key component in the binomial distribution is the use of factorials in performing the calculation. Visual C++ and Visual Basic would only allow the use of a factorial no greater than the value of 170 using variable type “double.” Double is the largest data type available in either of the two languages. Using a factorial this low was seen as a severe limitation in the ability of TUDM to process model inputs at any level above what would be considered a crude level of accuracy. The Java programming language offered a solution to this limitation through the use of their arbitrary precision arithmetic classes. Through the use of variables of Java type “BigInteger” and “BigDouble,” a factorial of any size could be calculated.

Utility Modules

The utility modules provide frequently used functions and subroutines that support the processing architecture (Figure 16). Contained within these modules are the ESRI constants, AML capabilities, strings collection, and file input and

output functions. Several of the ESRI AML capabilities provide the means by which the model extracts information from Arc/Info GRID files that are essential for model inputs. The ESRI strings collection also provides the means to receive prompts from the Arc/Info GRID object pertaining to the progress of Grid Analysis processing.

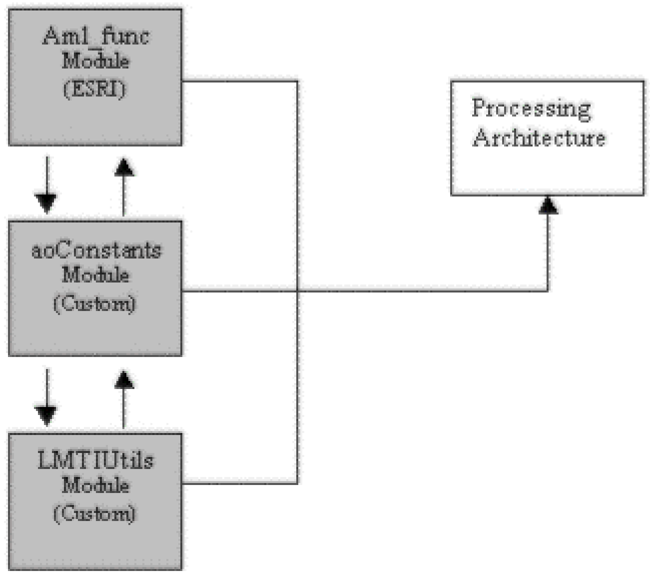

Figure 16. Object diagram of utility modules.

Model inputs are supplied through an Access database of information on training exercises based on Army Doctrine as presented in the ATTACC model (Anderson et al. 1996). The database contains the battalion name, description of an exercise, and relevant information concerning miles tracked, track widths, and percentage of tracking. To determine what percentage of an area is tracked by wheeled vehicles, the percentage tracked is subtracted from 100. The database also contains a table of probabilities for where a training exercise occurs based on past training exercise patterns. If the location of the exercise is not known, the user may select an option that uses this probability table to distribute training miles based on historical record. The data connection object is a Visual Basic object (Figure 17) that facilitates the link between the program and the Access database. In the TUDM model the database is connected to the model through the GUI, but it could just as easily be connected directly to the processing architecture if a program-to-program interaction was desired.

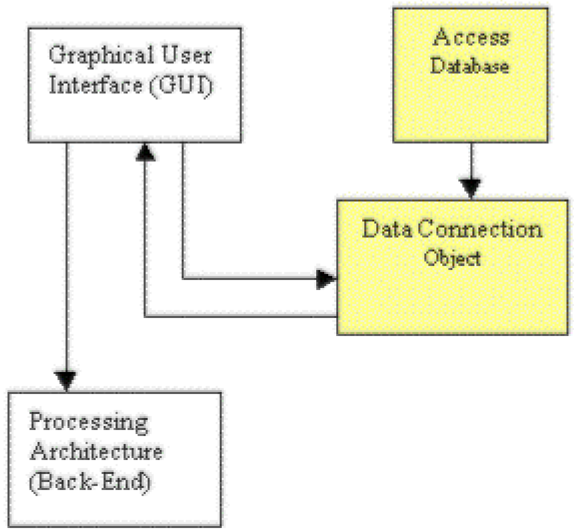

Figure 17. Access database of Army doctrine exercise inputs.

HTML Help System

The help system, written in the Hypertext Markup Language (HTML), was developed in Microsoft HTML Help Workshop. The help system consists of a tree structure of topics and content pages that are written in HTML. Each of the pages is viewed using the Microsoft Internet Explorer web browser. A complete set of content pages and topics are compiled into a help project file, which can then be linked to TUDM through the program's properties. Help can be invoked by pressing the F1 key or by clicking on a "Help" button or menu item. Clicking of either option elicits a Windows Application Programming Interface (API) call, which activates the help system and Internet Explorer. An example of the Help System interface is shown in Figure 18.

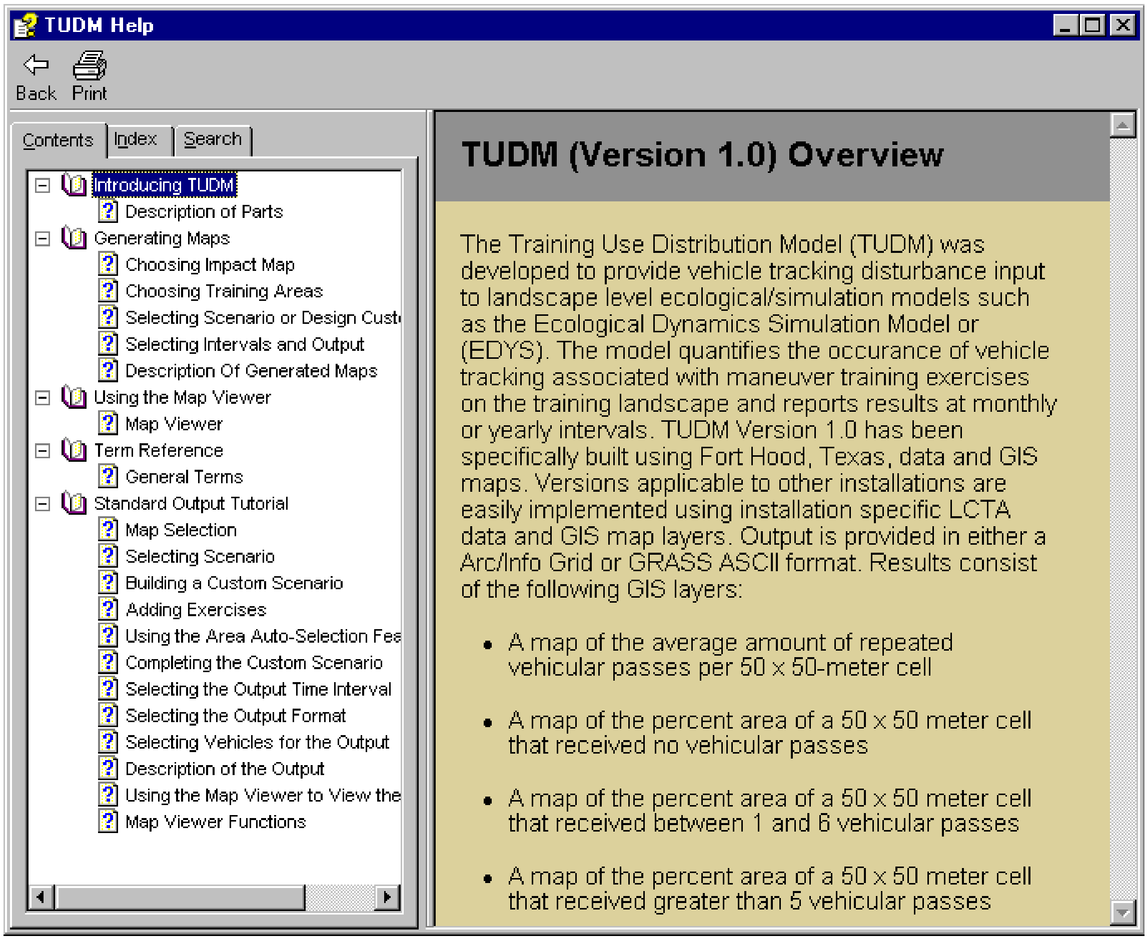

Figure 18. TUDM help system interface.

System Requirements

To run the prototype you must have the following Preferred System Requirement Configuration:

Pentium Class Processor 400 MHz or higher

512 MB RAM (minimum of 256 MB RAM)

6 Gigabyte or larger hard drive

Windows NT 4.0 Workstation w/service pack 3.0 or higher

Microsoft Internet Explorer 4.0 or higher

Work Station Arc/Info 7.2.1

Java Runtime Environment 1.2

During testing of the model it was found that exercise scenarios that contained more than 5 exercises with greater than 5 training areas required a processing configuration consistent with the preferred system requirements (512 MB RAM). However, scenarios of a lesser size may be successfully run with the minimum system requirement configuration (256 MB RAM).

3 MIDM Methodology and Fort Hood Validation

The MIDM methodology provides TUDM a means to distribute projected maneuver training miles across the training area landscape based on topography, vegetation, training use, and other factors that influence where maneuver impacts occur. The methodology produces a grid-based GIS map layer containing extrapolated Land Condition Trend Analysis (LCTA) disturbance data; the parameter is: percent of area disturbed by vehicle traffic. This map layer serves as a "probability surface" that defines areas most likely to be impacted by training maneuvers over a period of time exceeding a year, thus characterizing the overall pattern of maneuver disturbance on the landscape. Figure 19 shows this map layer. The probability of manueuver impacts ranges from high (approximately 70 percent in dark areas) to low (less than 5 percent in light areas). Low impact areas are most likely to contain restrictive terrain such as woodlands and steep slopes. MIDM was designed to be an economical method of analyzing maneuver patterns by making use of available installation data, thereby reducing the cost of implementation and reducing the need to develop new data sources.

Methodology

The MIDM methodology consists of fitting a generic logistic regression model (Equation 1) defined to account for the presence or absence of impact disturbance on the landscape, then applying the resulting equation in a grid-based GIS. The use of regression techniques to determine where activities occur on the landscape has been effectively used in range and wildlife management (Senft, Rittenhouse, and Woodmansee 1983; Van Manen and Pelton 1997). The underlying principle behind this type of modeling application involves correlating the dependent variable (in MIDM this is LCTA vehicle disturbance data) with independent variables that influence where the dependent variable occurs (in disturbance mapping the independent variables include topographic and physiographic features such as slope).

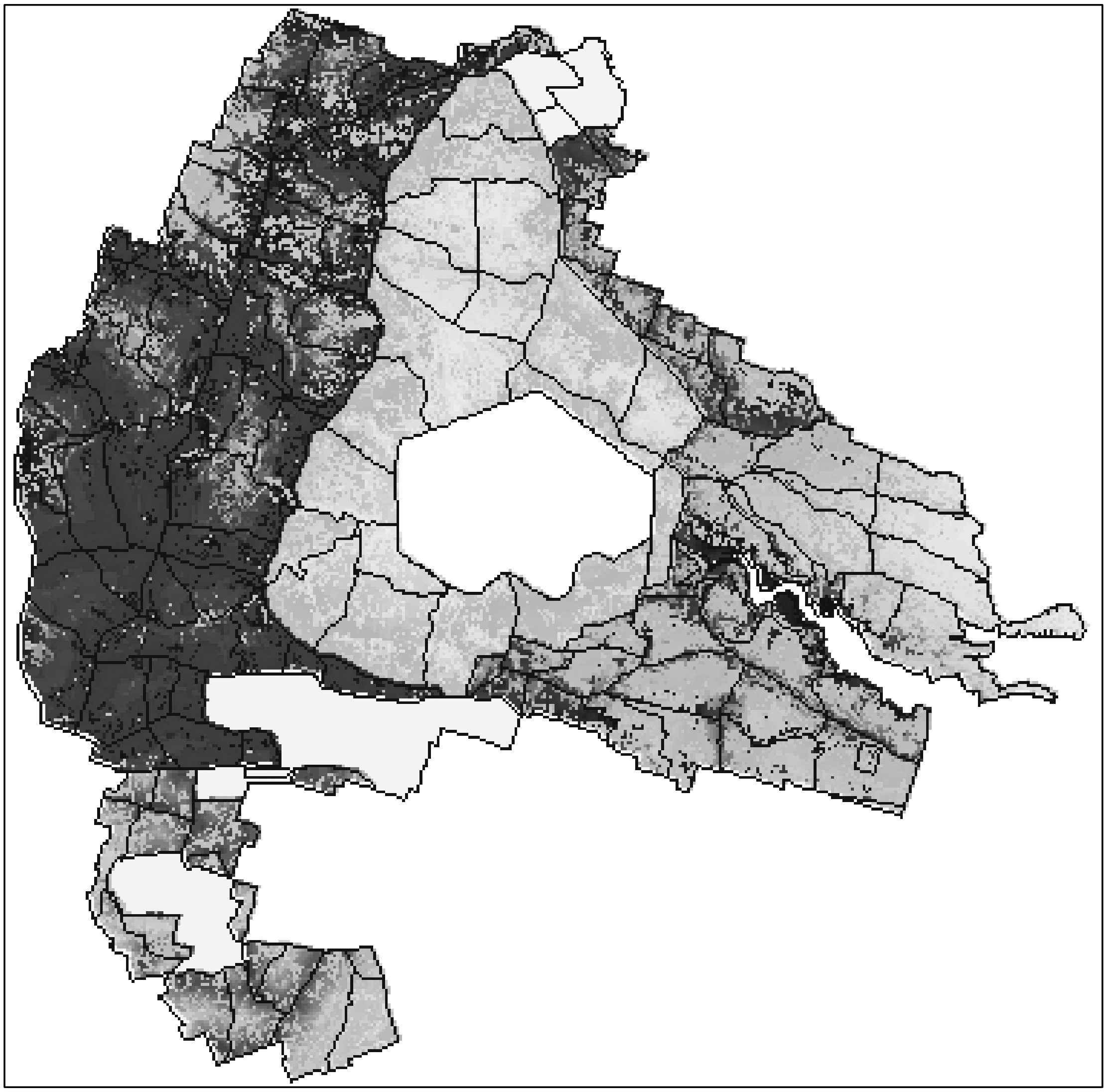

Figure 19. Fort Hood distribution map (showing probability of maneuver impacts ranging from high [approximately 70 percent in dark areas] to low [less than 5 percent in light areas]).

$$P_i = \frac{e^{\beta_0 + \beta_1 X_{1_i} + \ldots \beta_K X_{K_i}}}{1 + e^{\beta_0 + \beta_1 X_{1_i} + \ldots \beta_K X_{K_i}}} \qquad \text{[Equation 1]}$$

where: P_i = the historical percent disturbance on LCTA plot i (i.e., probability)

$\beta_0 \ldots \beta_k$ = the parameter estimates in the logistic regression equation

$X_{1i} \ldots X_{Ki}$ = the values of the independent variables

MIDM methodology was applied to data from Fort Hood, TX, for model development and validation. Fitting the logistic regression equation for Fort Hood was accomplished by using LCTA disturbance data as the dependent variable. Independent variables were: slope, vegetation type (defined as community structure, e.g., trees/woodland, brush/scrub, grass/open), distance from maintained roads, and installation region (groupings of training areas with similar training uses [Price et al. 1995]).

Dependent and Independent Variables

The use of LCTA disturbance data as the dependent variable is based on the fact that the LCTA methodology records the percentage of ground impacted by vehicle passes (Sprouse and Anderson 1995). Maximum disturbance values for plot measurements between 1990 and 1996 were used to account for a maximum value of potential plot disturbance.

The independent variables were selected based on two criteria. The first criterion is that these variables are easily obtained from most installation databases. The second criterion is that all the variables appear to have relevance in influencing the presence of disturbance, having p-values of approximately 0.05 in the model analysis (model R^2 was approximated at 0.4). These criteria are important because the focus of the MIDM modeling effort was to allow for easy transfer of modeling applications to a wide range of Army installations using data currently available at the installation (Guertin, Rewerts, and Dubois 1998).

Slope data was obtained from a GIS layer developed using a 50-meter Digital Elevation Model (DEM). The vegetation types originate from a GIS layer developed using a Normalized Difference Vegetation Index (NDVI) and derived from Landsat Thematic Mapper (TM) imagery (the best available representation of vegetation at the time of MIDM development). Both slope and vegetation type are documented as influencing the location of maneuver disturbance (Dubois 1994; Krzysik 1994). Installation regions were captured from plot locations within a map layer. Fort Hood is commonly divided into four training area regions: West, East, South, and Central (Price et al. 1995). Each region tends to have its own unique types of training activities based on topography, accessibility, and facilities. West Fort Hood is the major maneuver training ground; East Fort Hood is characterized by activities such as bivouacking and dismounted training; South Fort Hood is maneuver lands for mounted and dismounted activities; and Central Fort Hood contains live-fire ranges. The distance from maintained roads was developed by setting buffers in an installation roads file and then defining the distance based on LCTA plot locations within the buffers.

Roads tend to influence the accessibility of training lands within regions of the installation.

MIDM Validation

Two MIDM validation studies were conducted at Fort Hood, TX. The first study concentrated on a small area of Fort Hood and was conducted to facilitate model development. The second study was more comprehensive and covered the entire training landscape. Both studies compared MIDM disturbance values to field disturbance patterns. The studies consisted of collecting disturbance data from temporary field collection plots then comparing disturbance findings with those from the distribution map created for Fort Hood (Figure 19).

The plot design for both studies consisted of two 50-m transects that bisected each other at right angles (Figure 20). The first transect was aligned in a north-south direction, while the second was aligned in an east-west direction. Observations were recorded at 1-m intervals along the transects starting at the 0-m mark and ending at the 50-m mark; the 25-m (center) mark was not recorded. Recording observations in this fashion allowed for 100 records per plot, which is suitable for comparison to the LCTA plot. The center mark was surveyed with a Global Positioning System (GPS). The 50-m bisecting transect design was chosen to reduce the chance that a single, straight vehicle pass would disturb a majority of the plot—a scenario that is possible with the straight 100-m LCTA transect if the vehicle track coincided with (overlaid) the transect direction.

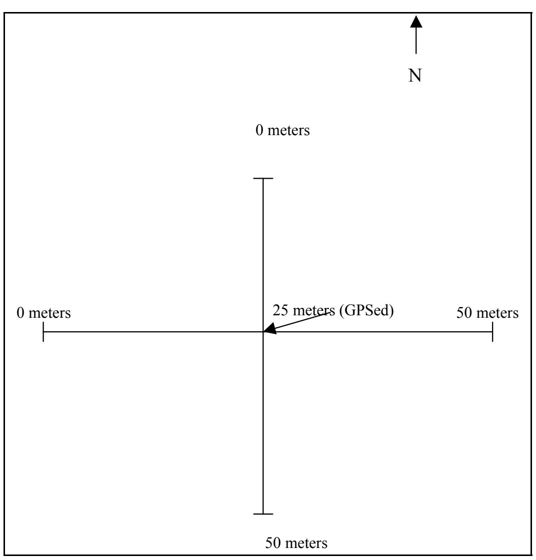

Figure 20. Validation plot design.

Information collected for each of the 100 points along the transects included: plot number, maneuver-training area, slope, aspect, Universal Transverse Mercator (UTM), vegetation type, and disturbance observations. Disturbance observations were recorded according to the point intercept method as used in LCTA (Tazik et al. 1992). For this validation study, only observations relating to possible vehicle traffic were recorded (as the model/map being validated predicts only vehicle impact distribution). Evidence of excavation, foot traffic, and other forms of disturbance were not included. Disturbance was recorded as either "NONE" (no visible disturbance present), "TRACKS" (a well-defined track print was present), "OLD TRACK" (evidence of tracking present, but not well-defined), and "EVIDENCE" (evidence of disturbance present, most likely vehicle related). Although disturbance categories were recorded separately in the field, all three disturbance categories were combined during analysis to reflect the "maximum potential" disturbance.

The first study was conducted during 2 weeks of June 1996 — the same year the disturbance map was constructed. LCTA disturbance measurements were taken from 41 locations in training areas 35 and 41 (Figure 21). Training area 35 is characterized by gently rolling land covered with open grasslands — a type commonly used for maneuver training exercises. Training area 41 is characterized by steep slopes and juniper forest/scrub land, which is less desirable for maneuvering and more commonly used for bivouacs. These areas were felt to adequately represent a major portion of maneuver training lands on Fort Hood. The sampling design consisted of a systematic random sample of plots located at 1000-m intervals across the training areas. Results from a comparison of MIDM values to field-recorded measures of vehicle disturbance showed extrapolated MIDM disturbance was underestimated (mean bias) by 5 percent (standard deviation of 3 percent) (Guertin, Rewerts, and Dubois 1998).

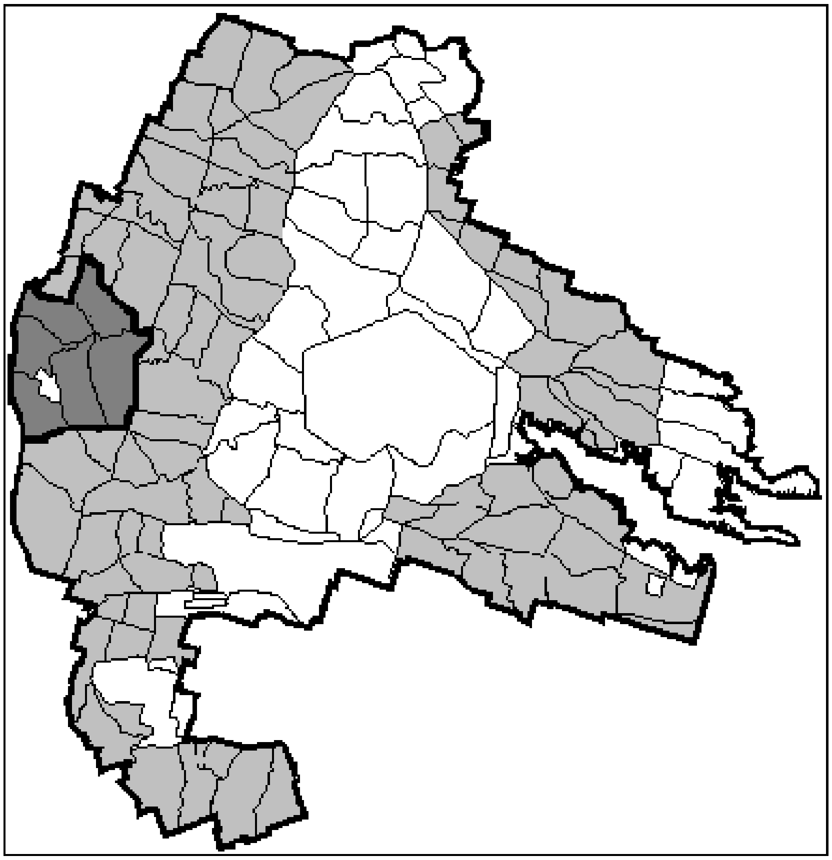

Figure 21. Fort Hood training areas sampled in validation studies (dark shaded areas sampled in 1996, all shaded areas sampled in 1998).

The second validation study occurred during the last 2 weeks of September and first week of October 1998. This study was a more comprehensive version of the 1996 study and was designed to judge MIDM performance across the whole installation. Validation plots were based on random stratified sampling methods. Sample allocation was based on vegetation type and training area region; both are factors used in calibrating the distribution map. Plots were distributed with the aid of a GIS. In this process, the two GIS layers representing the sampling stratum were merged into a single "strata" layer and plot locations were randomly assigned in proportion to area represented by each stratum in the strata layer. Plots were located in the field with a GPS. Once located, each plot was compared to the stratum it was to represent. If they were not the same, an alternate plot was randomly selected at the closest available location that represented the stratum. Additionally, slope was considered in determining the final plot placement because it is a factor that influences disturbance. Plots were added as needed to cover the range of slopes occurring in the training areas. Because the West region is the site of most maneuver training, the first 2 weeks of fieldwork concentrated on that area. The last week of fieldwork concentrated on

the East and South regions. A total of 223 validation plots were completed; the breakout between region and vegetation type are presented in Table 1.

Table 1. Validation plots by region and vegetation type.

Region	Sample Size (plots)	Vegetation Type	Sample Size (plots)
West	197	Grass/Open	149
		Scrub/Brush	38
		Tree/Woodland	10
East	12	Grass/Open	2
		Scrub/Brush	5
		Tree/Woodland	5
South	14	Grass/Open	9
		Scrub/Brush	2
		Tree/Woodland	3

Summary statistics for the validation data set and the corresponding data from the same coordinates of the MIDM Fort Hood distribution map are presented in Tables 2 and 3. An initial examination of mean disturbance as recorded in the validation data shows higher tracked disturbance in West Fort Hood as opposed to East and South Fort Hood. Tracking disturbance was found to be present at higher levels in grass/open terrain, with scrub/brush areas being lower, and woodlands being the lowest. These patterns are consistent with the Fort Hood distribution map.

Two statistical analyses were selected to determine how well the MIDM represented the maneuver disturbance conditions on Fort Hood training areas. The first analysis was to determine the overall mean bias (and standard deviation) of actual map values versus predicted values. This analysis allows determination of how well the model predicts the magnitude of disturbance at any given location. The second analysis used was the Spearman's Rank Correlation Coefficient. The Spearman test allows determination of how well the overall disturbance pattern represented by the MIDM matched the Fort Hood landscape pattern. These two statistics together help define the practicality of using the MIDM as a "probability" map for placing future disturbances.

Table 2. Mean validation disturbance across installation region and vegetation type.

Region	Mean Disturbance (%)	Standard Deviation	Sample Size (plots)	Vegetation Type	Mean Disturbance (%)	Standard Deviation	Sample Size (plots)
West	38.5	18.5	197	Grass/Open	45.0	13.9	149
				Scrub/Brush	22.4	15.9	38
				Tree/Woodland	3.5	7.0	10
East	16.3	14.2	12	Grass/Open	43.0	4.2	2
				Scrub/Brush	14.0	4.1	5
				Tree/Woodland	7.8	9.0	5
South	14.8	11.3	14	Grass/Open	22.0	6.4	9
				Scrub/Brush	3.5	0.7	2
				Tree/Woodland	0.7	1.2	3

Table 3. Mean extrapolated disturbance across installation region and vegetation type.

Region	Mean Disturbance (%)	Standard Deviation	Sample Size (plots)	Vegetation Type	Mean Disturbance (%)	Standard Deviation	Sample Size (plots)
West	61.8	10.3	197	Grass/Open	63.2	8.5	185
				Scrub/Brush	44.3	6.9	9
				Tree/Woodland	25.7	0.6	3
East	29.6	10.6	12	Grass/Open	37.5	12.0	4
				Scrub/Brush	27.3	6.7	7
				Tree/Woodland	14.0	*	1
South	27.4	11.3	14	Grass/Open	29.1	11.4	12
				Scrub/Brush	17.5	2.1	2
				Tree/Woodland	*	*	0

A comparison of percent disturbance occurring on all validation plots with percent disturbance values from the MIDM disturbance map revealed a mean overestimation (mean bias) of map values by 22.1 percent with a standard deviation of 16.8. Validation statistics (Gribko and Wiant 1992) for mean bias and standard deviation are presented in Equations 2 and 3.

$$\text{Mean Bias} = \frac{\left(\sum (\mathrm{P_i} - \mathrm{O_i})\right)}{\mathrm{n}}$$

[Equation 2]

$$\text{Standard Deviation} = \sqrt{\frac{(\sum (\mathrm{e_i} - \bar{\mathrm{e}})^2)}{(n-1)}}$$

[Equation 3]

where: P_i = extrapolated value

O_i = observed value

n = number of observations

e_i = error, defined as $(P_i - O_i)$

$\bar{e}$ = mean error, $\frac{\sum e_i}{n}$ for all i.

Results from actual versus predicted values separated by region and vegetation type are presented in Tables 4 and 5. Over-predictions and variation were highest in the West region where a majority of maneuver activity occurs, although "grass/open," where maneuver training is most likely to occur, had a lower bias than any other vegetation type.

Table 4. Extrapolation comparison based on installation region (all biases are overestimates).

Region	Statistic	Value	95% Confidence Interval (+/-)	Sample Size (plots)
West	Mean Bias (%)	23.3	2.4	197
	Standard Deviation	17.2		
East	Mean Bias (%)	13.3	6.1	12
	Standard Deviation	10.9		
South	Mean Bias (%)	12.6	5.1	14
	Standard Deviation	9.6		

Table 5. Extrapolation comparisons based on vegetation type (all biases are overestimates).

Vegetation Type	Statistic	Value	95% Confidence Interval (+/-)	Sample Size (plots)
Grass/Open	Mean Bias (%)	18.5	2.3	160
	Standard Deviation	15.2		
Scrub/Brush	Mean Bias (%)	30.8	2.2	45
	Standard Deviation	17.6		
Trees/Woodlands	Mean Bias (%)	31.2	8.1	18
	Standard Deviation	17.4		

The accuracy of the MIDM predicted disturbances fluctuated considerably between the 1996 study and the 1998 study. Explanations for this fluctuation, and the inaccuracies (mean biases) in general, can be attributed to a number of factors. First, the techniques used in LCTA (and this study) to measure disturbance are subjective (due to obsever experience and bias). Second, measurements are affected by field conditions at the time of vehicle traffic and/or time of observation. The nature of LCTA techniques guarantees some amount of difference between observed and predicted values. Third, the MIDM map was pro-

duced using a relatively low resolution vegetation map, and other GIS data layers. Data of this nature introduces error into the modeling process. Comparisons of 1998 plot-recorded vegetation type versus vegetation type represented in the vegetation map used for calibration showed that 61 percent of the plots that should have been located in "tree/woodlands" were actually in "grass/open" terrain. Whereas less than 1 percent of "grass/open" plots were misclassified as "tree/woodland." Finally, the LCTA data used to develop the Fort Hood map represented "potential" maximum disturbances over a 5-year period of time (1991 through 1996), while both studies recorded annual disturbances. Given that the calibration data set was not large enough to produce both a statistically significant model and a separate, independent validation data set, collecting annual data was the best possible solution. Mean biases of approximately 20 percent are reasonable to consider the MIDM as successful in terms of predicting locational disturbance magnitudes.

To determine if the overall pattern of disturbance across the training areas matched that of the disturbance map, Spearman's Rank Correlation Coefficient was used. The Spearman test reports values between 1 and –1; values approaching 1 indicate a correlation between map and training land values, while values approaching -1 indicate negative correlation (0 indicating no relationship at all). A comparison of disturbance map values with those collected in the field resulted in an overall ranking of .54 ($p < .001$), with a regional range from .40 to .65 (Table 6). These results indicate that the disturbance pattern modeled by MIDM approximates the overall landscape pattern found on Fort Hood maneuver training lands.

Table 6. Spearman's rank order correlation (r_s) results by region.

Region	Sample size (plots)	r_s	P
Total	223	.54	<.001
West	197	.40	<.001
East	12	.65	.20
South	14	.64	.05

4 Summary

The Training Use Distribution Model was developed to provide long-term predictions of distributions and intensities of off-road Army maneuver-training impact for carrying capacity and other ecological simulation models, especially EDYS. The current working version of TUDM was developed for Fort Hood, Texas.

Although, TUDM projections have not yet been validated, the MIDM distribution component has been. Validation studies indicate reasonable results in terms of predicting locational disturbance magnitudes, given the resolution of data used to calibrate the model. Results also indicate that the disturbance patterns modeled by MIDM generally match the overall landscape pattern found on Fort Hood maneuver training lands.

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14. ABSTRACT

Since the early 1980's, researchers and land managers from ERDC/CERL have been developing means to quantify and predict sustainable vehicle use rates associated with maneuver training exercises for Army training lands. Two new projects include: (1) Army Training and Testing Areas Carrying Capacity model (ATTACC), and (2) the Ecological Dynamics Simulation model (EDYS).

To incorporate the effects of maneuver impacts as ecological stressors into the EDYS model, researchers developed the distribution pattern ideas used within ATTACC and incorporated them into a GIS environment to allow for long-term distribution and intensity estimations. The product resulting from this effort is the Training Use Distribution Model (TUDM).

The TUDM was developed to provide long-term predictions of distributions and intensities of off-road Army maneuver-training impact for carrying capacity and other ecological simulation models.

This report contains an in-depth description of TUDM structure and architecture, along with the individual components. Validation studies indicate reasonable results in terms of predicting locational disturbance magnitudes, given the resolution of data used to calibrate the model. Results also indicate that the disturbance patterns modeled generally match the overall landscape pattern found on the maneuver training lands.

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